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Analysis of the Department of Defense Global Asset Visibility Technology Demonstration, 23-26 February 2004, DDJC

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Abstract

This report presents an analysis of and documents the significant learnings from the Department of Defense Global Asset Visibility Technology Demonstration held at DDJC, Tracy, CA from 23 February 2004 through 26 February 2004 and its preparation. The Technology Demonstration successfully demonstrated the capabilities of passive and semi-passive radio frequency identification (RFID) technologies to enable the automated identification of Class 1 objects as they move through a military supply chain. Furthermore, the Technology Demonstration successfully demonstrated the capabilities of a data management system to utilize unique item identification, aggregation, and read location to accurately track and trace all tagged items. Some of the limitations in the RFID technologies were demonstrated as well as some preliminary reader implementation layouts that could be used in practice.

Preface

This report details my analysis of and significant learnings from the DoD Global Asset Visibility (GAV) Technology Demonstration. I had the privilege of participating in the Demonstration in the capacity of expert technical advisor to the DoD Natick team. In the role of expert technical advisor I had the opportunity to educate the Natick team on the technology, suggest directions for the high-level technical directions of the technology, and provide expert opinions on various events that occurred during the development, testing, and demonstration phases of the project.

As the Research Director of the Auto-ID Labs of MIT, one of the principle architects of the base system used to conduct the demonstration, and the Technology Project Manager for a large-scale Field Trial conducted by the Auto-ID Center of MIT, I am uniquely qualified to understand both the theoretical and the practical aspects of the design and use of the technology. As an unbiased expert, I was able to draw upon my knowledge and experiences to educate the Natick team on the events and activities of the demonstration as well as education on the workings of RFID systems and the EPC System. As an expert technical advisor, I did not have an active role in implementing or running any of the activities surrounding the Technology Demonstration.

From my vantage point outside of the implementation team, I had the opportunity to observe the implementation output and participate in the planning sessions and group meetings held with the Natick team. This level of participation gave me access to the end products and checkpoints of the implementation team but not to the internal discussions and decisions made within the implementation team. This ultimately limited my observations, and, thus, my analysis and learnings documented in this report.

The learnings and opinions presented in this report are based solely upon my knowledge and my observations and participation within the Technology Demonstration and the activities associated with it.

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1 Executive Summary

The DoD Global Asset Visibility Technology Demonstration, the "Demonstration," held at the Defense Distribution Depot, San Joaquin, CA (DDJC), Tracy Facility, in Tracy, CA, from 23 February 2004 until 26 February 2004, was the first large-scale demonstration of the capabilities of passive and semi-passive radio frequency identification (RFID) technologies and EPC System technologies within the Department of Defense's (DoD's) Class 1 supply chain. The Demonstration showed that passive and semi-passive RFID technologies and the EPC System enable unique item level identification, tracking, and tracing throughout the entire DoD supply chain by allowing for low, or no, human intervention automatic unique item level identification. Consequently, the Demonstration showed that RFID technologies have the capability to deliver complete global asset visibility for all items within the DoD's supply chains.

1.1 Necessity for new Asset Visibility Technologies

Complete Global Asset Visibility (GAV) of all consumable and reusable assets is essential to the efficient and cost effective movement of product and the total readiness of the armed services. GAV enables right product, right place, right time; resulting in increased troop readiness at the lowest possible cost.

Complete global asset visibility is not a reality today due to the limitations of human operations, particularly in-theater operations, and the limitations of deployed automated identification and data capture technologies, including bar code technologies and container RFID technologies. The primary limitations of today's processes and technologies are an inability to automatically and uniquely identify all objects, at all levels of granularity, everywhere with little or no human intervention.

RFID technologies, including passive RFID, semi-passive RFID, and active RFID, combined with EPC technologies, have the potential to provide complete global asset visibility economically and at all levels of granularity.

1.2 Objectives of the Technology Demonstration

The objectives of the Demonstration were to demonstrate the ability of passive and semi-passive RFID tags combined with the EPC System control and data management technologies to track inventory in an end-to-end Class 1 supply chain and to demonstrate the ability of sensor-equipped RFID tags to provide quality and shelf-life data.

1.3 Technology Demonstration Summary

The DoD Global Asset Visibility Technology Demonstration simulated the pallet building and movement of Meals Ready to Eat (MREs) and Unitized Group Rations (UGRs) beginning within a Depot and flowing through a General Support (GS) supply point and then through a Direct Support (DS) supply point. Each MRE and UGR was tagged at the case level with a 915MHz passive RFID tag during the pallet building process within the Depot. A unique Electronic Product Code (EPC) was written to each passive tag. Each physical pallet was tagged with a 2.45GHz semi-passive RFID temperature sensing tag. Each pallet tag was programmed with a unique pallet EPC and the manifest of the EPCs of the items on the pallet. Pallets were loaded into containers that were tagged with a 2.45GHz semi-passive RFID tag. Unique container EPCs and load pallet EPCs (the manifest) were written to container tags. Similarly, pallets were loaded onto flatbed trailers that were tagged with a 2.45GHz semi-passive RFID tag. A unique trailer EPC and load pallet EPCs (the manifest) were written to each trailer tag. A representative subset of temperature profiles collected by the pallet tags were downloaded upon arrival at the GS, and the quality of the pallet contents were estimated based upon this profile. For pallets contained within the same container, the temperature profile from a single pallet within that container was used to estimate the quality of all items within the container.

Ten locations within the simulated supply chain were instrumented with RFID readers. These locations were identified as a representative set of locations where reading of the RFID tags would enable the track and trace of the product through the military Class 1 supply chain up to the point of issue. These locations and their objectives are delineated in the following.

- **Station 1 - Case Commissioning-Pallet Building:** The objective of Station 1 was to build pallets where all cases on a pallet are tagged and assigned a unique EPC and the pallet manifest of on-pallet case EPCs is written automatically to the pallet tag. Built pallets are automatically added to the depot inventory.
- **Station 2 - Container Loading:** The objective of Station 2 was to load a container with pallets and automatically write the container manifest of loaded pallet EPCs to the container tag. Pallets loaded into a container are automatically removed from the depot inventory and added to the in-transit inventory.
- **Station 3 - GS Supply Point Entry:** The objective of Station 3 was to identify the container tag and read its manifest data as the container entered the GS. All pallets contained in the manifest are automatically added to the GS bulk storage inventory.
- **Station 4 - Quality Update:** The objective of Station 4 was to determine the quality of the MREs and UGRs contained in a container. The temperature data from a single pallet tag within the container is read. That temperature profile is utilized to calculate the quality of all pallets within the container.
- **Station 5 – Issue Portal:** The objective of Station 5 was to identify all pallets as they are moved from the bulk area of the GS into the issue area of the GS.
- **Station 6 – Flatbed Loading:** The objectives of Station 6 were to load a flatbed trailer with pallets and automatically write the trailer manifest of loaded pallet EPCs to the trailer tag.
- **Station 7 – GS Supply Point Exit:** The objectives of Station 7 were to identify a trailer as it exits the GS issue area and to automatically decrement the GS inventory.

- **Station 8 - DS Supply Point Entry:** The objectives of Station 8 were to identify the trailer tag and read its manifest data as the trailer entered the DS. All pallets contained in the manifest are automatically added to the DS inventory.
- **Station 9 – Issue Portal:** The objective of Station 9 was to identify pallets as they are moved into the DS issue area.
- **Station 10 – Unit Issue:** The objective of Station 10 was to verify the correct inventory of the unit piles in the DS issue area.

1.4 Technology Demonstration Conclusions

The DoD Global Asset Visibility Technology Demonstration successful demonstrated the capabilities of passive and semi-passive RFID tags and the EPC Network to track and trace Class 1 inventory, in real time, as the products move throughout the DoD's supply chains. Objectives were achieved at each station throughout the Demonstration during the period 23-26 February. The Demonstration highlighted both the capabilities of and the limitations of the technologies used. Existing technologies are immature but currently capable of providing significant automated identification capabilities and their attendant benefits. While immature, the technologies are clearly capable of being developed further to meet the strict requirements for use within the DoD's supply chains.

2 Demonstration Implementation

2.1 Demonstration Technology

OATSystems was the general contractor and integrator for the Demonstration. Unique identifiers were used to identify all cases, pallets, trailers, and flatbeds utilized in the Demonstration. The Electronic Product Code (EPC) was used as the object identifier.

OATSystems developed the software applications and supplied the Savant technology for the Demonstration. The Savant technology provided the base operating environment for the applications. The applications were created to enable supply chain visibility throughout the life of an object. These applications were implemented to be Demonstration specific; however, they were designed and implemented to be scalable and simulate a real-world deployed implementation.

A physically different computer was used for the centralized databases and applications for each of the three main Demonstration areas: Depot, GS, and DS.

The RFID systems were supplied by Alien Technologies. Two different types of RFID technologies were utilized in the Demonstration: 915MHz passive RFID systems and 2.45GHz Battery Assisted Passive, or semi-passive, temperature sensor RFID systems. The 915MHz systems were utilized to identify cases of MREs and UGRs. The 2.45GHz systems were utilized to identify pallets, containers, and flatbed trucks. The 2.45GHz systems were also utilized as manifest tags, storing the EPCs of all items contained either on or within the object. The 2.45GHz tags contained an on-tag temperature sensor that was used to collect temperature data for the quality control applications.

An Alien single antenna 915MHz reader was utilized for the case tag commissioning within the Depot. Alien four antenna 915MHz readers were utilized for forklift portals within the GS and the DS. A Symbol handheld reader was utilized to read 915MHz tags on unit piles within the issue area of the DS. Alien 2.45GHz dual antenna readers were utilized within all stations that required the reading and/or writing of a 2.45GHz tag.

One 2.45GHz reading system was integrated into each of two mobile platforms. The mobile 2.45GHz reader systems were used to read tags and temperature history in the receipt of containers at the GS, to read pallet tags on loaded flatbed trailers, and write the flatbed trailer tag and manifest in the issue area of the GS.

Alien Technologies integrated three 2.45GHz readers into a forklift. Two readers were integrated in the fork cage of the forklift. The cage readers were designed to read pallet tags of pallets being moved by the forklift. Antennae for the two readers were positioned such that the pallet tag of both the bottom pallet and a second stacked pallet could be read while being moved by the forklift. For the Demonstration, the cage readers were used to write data to the container tags. The third 2.45GHz reader was situated on top of the forklift to read the container tag during the loading process at the Depot.

The forklift systems communicated with the applications servers and databases by using a 2.45GHz 802.11b wireless network. Linksys wireless network equipment was utilized. The portable readers also utilized Linksys wireless network equipment. All fixed location network connections utilized wired Ethernet network connections.

2.2 Demonstration Process

There were a total of ten (10) stations identified for specific demonstration points. These stations are representative of some of the critical locations within the DoD's Class 1 MRE and UGR supply chains. Intermediate transit points for containers and intermediate warehouses are not represented within these ten stations. For each station, material handling processes were designed to closely model the processes used in practice; thereby enabling the Demonstration to closely represent the existing supply chain practices. The high-level process steps used at each station are described below.

- **Station 1 - Case Commissioning-Pallet Building (Depot):**
  - Pallets are tagged with 2.45GHz Manifest Battery Assisted Passive tag
  - Pallet tag is Commissioned (Pallet EPC written and data management system notified that pallet building process has begun).
  - Cases are tagged, one at a time, with a 915MHz passive identity tag.
  - Case tag has EPC written to it.
  - Case EPC associated within Senseware database to pallet being built.
  - Repeat for all cases.
  - After all case tags written and pallet built, Pallet Tag manifest is written with all case tag EPCs.
  - 915MHz Check tag applied to full pallet.
  - Senseware associates Check tag with pallet.
  - Pallets are automatically added to the Depot inventory.

- **Station 2 - Container Loading (Depot):**
    - Container is tagged with a 2.45GHz Manifest Battery Assisted Passive tag.
    - Container tag is Commissioned.
    - 2 stacked pallets picked up by forklift.
    - 2.45GHz pallet tags read by forklift readers.
    - Forklift enters container and roof forklift reader reads container tag.
    - Pallets are associated with container within Senseware.
    - Forklift repeats until container is loaded.
    - Container tag manifest is written with loaded pallet EPCs.
    - Depot inventory is automatically decremented as the container tag is written.
- **Station 3 - GS Supply Point Entry (General Support (GS) Supply Point):**
    - Container tag is read at entry (manifest and container identity)
    - Container and pallet EPCs automatically entered into GS bulk storage inventory.
- **Station 4 - Quality Update (General Support (GS) Supply Point):**
    - Container opened upon receipt at GS.
    - Portable 2.45GHz reader acquires temperature data from one pallet tag.
    - Computer shelf life model uses acquired temperature data to estimate quality of pallet contents for each pallet within the container.
    - Pallets identified as "issue," "inspect," or "reject."
    - Pallets are made available for pick lists
- **Station 5 – Issue Portal (General Support (GS) Supply Point):**
    - Based on pick list and remaining product quality, pallets are selected and moved, one at a time, through a 915 MHz portal reader to GS issue area.
    - Pallet check tags are read by portal.
    - GS bulk storage inventory automatically decremented.
    - GS issue area inventory automatically incremented.
- **Station 6 – Flatbed Loading (General Support (GS) Supply Point):**
    - Logistician inputs shipment data.
    - 2.45GHz tag placed on flatbed trailer in issue area.
    - Trailer tag is Commissioned.
    - Tagged pallets loaded onto flatbed in issue area.
    - Portable 2.45GHz reader reads all pallet tags loaded on trailer.
    - Trailer tag manifest written with loaded pallet EPCs.
- **Station 7 – GS Supply Point Exit (General Support (GS) Supply Point):**
    - Flatbed trailer tag is read at GS Supply Point exit
    - GS inventory is automatically decremented as flatbed trailer tag is read.
- **Station 8 – DS Supply Point Entry (Direct Support (DS) Supply Point):**
    - Trailer tag is read at entry (manifest and container identity).
    - Trailer and pallet EPCs automatically entered into DS bulk storage inventory.
- **Station 9 – Issue Portal (Direct Support (DS) Supply Point):**
    - Pallets are moved through a 915 MHz portal reader to DS issue area.
    - Pallet check tags are read and DS bulk and issue area pallet level inventory adjusted.

- **Station 10 – Unit Issue (Direct Support (DS) Supply Point):**
    - Unit piles established in issue area based on requisitions
    - DS logistician inputs unit info for each unit pile on a handheld reader
    - Handheld 915 MHz reader used to read passive pallet tags & loose case tags
    - Senseware decrements DS inventory and associates products with units
    - Unit supply personnel pick up unit piles at the DS issue area

3 Demonstration Analysis

The Demonstration and its preparation yielded many insights into the capabilities, limitations, readiness, and deployment issues of RFID systems. The primary insights are delineated in this section.

3.1 Interface to the System

The Demonstration highlighted the need for effective software interfaces. These interfaces are even more critical in demonstrations due to the need to expose the inner workings of the system. The interfaces are the windows into the internal workings of the data management and control systems. Exposing the inner workings of a system is essential to illustrate, within a demonstration setting, the capabilities of a system. Simply showing the end results (even though proper in an operational setting) has a magic quality that often leaves the demonstration visitors with a sense of disbelief; thereby, decreasing the overall impact of the demonstration.

Many critical features of interfaces were identified. The interfaces must contain intuitive process control screens that guide the user through the process steps and clearly identify any errors or exceptions that occur. The interfaces must utilize large fonts and buttons for easy operator viewing and navigation. The interface must contain minimal information on-screen for intuitive and simple understanding by the operator. Real-time monitoring tools are required, particularly for demonstrations, to allow the personnel to visually see the actions occurring in the software systems. The ability to see operational details on demand is critical for identifying problems and debugging their cause. The operational details should not need to be seen by an operator during normal operations.

3.2 Operational Processes

The defined operational processes were adequate for the Demonstration. The processes were representative of the activities and steps required in practice, although they were not necessarily the exact processes used in practice. The viability of the Demonstration processes for operational use was not verified by their actual use within a live operation. A full-scale pilot of RFID technologies will be required to refine the operations.

The manual pallet building process is well defined, controlled, straight forward, and equivalent to the manual process that would be employed in practice. The process is easily controlled and implemented. The greatest difficulty is ensuring that a single tag is in the reader field when the identifier is written to the tag. A production implementation will have the case commissioning and pallet building automated.

3.3 Semi-Passive Tags

The 2.45GHz semi-passive tags were found to be capable manifest and temperature sensing tags. The directional passive communication of these tags requires the use of properly positioned reader antennae for communication. Sufficiently obstructed tags cannot be read. For 2.45GHz tags, sufficient obstructions may be liquid on the antennae. The range and reliability limitations on passive communication limit the applicability of passive and semi-passive tags in long range, inclement weather, and obstructed communications. Consequently, the use of semi-passive tags to identify containers and trailers at long range must be accompanied by good system design that overcomes and takes advantage of the limitations of passive communication.

A full scale study comparing the advantages, disadvantages, benefits, and costs of using active tags versus semi-passive tags for longer range communications must be undertaken.

3.4 Passive Tags

915MHz passive tags have sufficient performance to be used in item level tagging in the Class 1 supply chain. Class 1 items are typically identified at short range (often less than 3m) while pallets and containers may need to be identified at longer ranges.

Analysis of the tag data indicates that defective 915MHz passive tags accounted for up to 4% of all tags applied to the cases. For tags applied at Station 1 pallet building during the Demonstration, the failure rate was 1% (one tag in the one hundred applied tags was found to be defective). The 915MHz tags were supplied as labels on a roll of labels. Labels that tested below the minimum quality were removed from the roll by the tag manufacturer (Alien Technologies). The resulting gaps in the roll of labels would have caused difficulties with existing automated label machines which assume all labels are present on a roll. Next generation label printers and programmers will be able to handle bad tags and missing labels.

The level of defects experienced within the Demonstration and evidenced by the manufacturer removed labels is a clear indication of the low maturity level of the passive tags utilized in the Demonstration. Mature products typically have a failure rate well below one percent. It is expected that the experienced defects will decrease to the sub one percent rate as the product matures.

Initial testing of the 915MHz passive tags indicated that they could not be read reliably when affixed directly to the cases of MREs and UGRs. The difficulties occurred primarily during wet/damp MRE case testing. The tag antennas were not designed to work on cases of wet MREs and UGRs. Instead, they were general purpose tag antennae designs. The reduced reliability of tag reads experienced during testing is due to the high metal content of the MRE and UGR cases and the high moisture content of the case packaging on the tested MREs.

Passive tags require either separation from metal to be read or an antenna designed to work on or near metal. Metal in close proximity to an antenna can de-tune the antenna; thereby decreasing its efficiency at one (typically the desired) frequency while increasing its efficiency at another (typically not desired) frequency. Testing indicated that the cardboard packaging provided sufficient separation from the MRE metal foil to enable tag communication on dry cardboard packaging. Initial testing also indicated that metal contained within the UGRs may have an impact on read reliability.

Liquids absorb radio frequency (RF) energy and, similar to metals, can de-tune a tag antenna. High moisture content case packaging absorbs RF energy and detunes tag antennae affixed directly to it. Since the case packaging had variable moisture content, the read reliability was variable when the tag was affixed directly to the case packaging.

3.5 Passive Tag Packaging

Special tag packaging was utilized to reduce the variability in read performance that can be caused by the moisture content of the case cardboard packaging and any metal that may be contained within the case. The special packaging used on the tags was double sided tape. The tape provided separation between the tag and the package, thereby separating the tag from any metal in the case or liquid in the packaging of the case. The use of this special packaging reduced the variability of tag performance that could be caused by the presence of liquids and metals. Good, reliable read performance was achieved during the Demonstration.

The use of a spacer increases the cost of the tag and makes the tag more susceptible to damage from normal use since it protrudes from the packaging. The long-term plan should be for the tag to be integrated into the cardboard packaging. This integration will require the tag to work properly and with required performance levels in close proximity to metal. This may be achieved with the properly designed tag antenna. The tag must also communicate at the required range even though the moisture content of the packaging will vary. This variability will necessitate the design of a tag antenna that operates within parameters over a wide range of moisture levels.

3.6 Software Requirements

915MHz passive tags could not be read while in the middle of the pallet of MREs due to the high metal content within the MRE cases. The inability to read all tags requires the software system to maintain the associations of cases to pallets. Aggregation ensures proper asset management even though all tags may not be read.

3.7 Operations

A single 915MHz passive tag was used as a Check Tag. The Check Tag was used to indicate that the pallet was intact. This is required due to the inability to read all case tags on the pallet. The use of a single tag causes the reading of the pallet to be orientation sensitive. At least two Check Tags, located on diagonally opposing corners, should be used to eliminate the orientation sensitivity of the pallet reading. Ideally, each tag will be readable over a 270 degree unobstructed field of view. This will allow at least one tag to be separated from the forklift truck while being carried, thus improving its ability to be read. In this configuration, at least one tag will be readable by a portal reader regardless of which side of the portal the reader's antennae are situated.

3.8 Portal Readers

The 915MHz portable portal configurations utilized a single reader with four antennae. The antennae were arranged with two antennae on each side of the portal. This necessitated a wire to be run between opposing sides of the portal. Running this wire is impractical in practice due to the fragility of this wire. Wires run along the ground will be run over by forklift trucks and are susceptible to being destroyed. It is generally not feasible to bury the wires. Running wires above the portals makes them susceptible to being damaged by large or tall loads brought through the portal.

A simpler portal design would utilize one reader (with its connected antennae) on each side of the portal. No wires would need to exist between sides of the portal; thereby, eliminating the possibility of damaging the antenna wiring. The two readers reading a portal (one on each side of the portal) would need to be coordinated so as not to interfere with one another's operations. They may coordinate either through a central coordination point or by coordinating between themselves.

The antenna set-up of the 915MHz portable portals required significant time, testing, and expertise. This type of set up is not generally feasible in a field environment. Instead of attempting to minimize the number of antennae and readers, the portal design must be over engineered so that set-up is simple, place the preconfigured antenna pole in the ground and connect the wires, and works as expected, pre-test the antenna pole. An over-engineered solution is forgiving to disturbances and improper installation. Optimal RFID reader antenna configurations have been found to be fragile, that is, susceptible to disturbances both in practice and in the preparations for the Demonstration.

3.9 Radio Frequency Interference

The Demonstration utilized a 2.45GHz wireless LAN configuration for communication with the forklift readers and the portable reader. The 2.45GHz semi-passive readers were found to interfere with the communication of the wireless LAN devices. When two distinct wireless systems, communicating at the same frequency, are operating in close proximity to one another, they must be physically configured so that they do not interfere with one another. This is particularly true of RFID systems that operate at maximum allowable power levels. In general, it is good system design to operate RFID systems in different frequency ranges from other wireless systems. RFID systems typically operate at maximum allowable power levels which can interfere with devices operating at less than maximum power levels.

An occasional lack of connectivity may be expected in theater operations. Thus, the RFID and applications systems must be designed to operate robustly without connectivity.

4 Summary

The DoD Global Asset Visibility Demonstration achieved its goals by successfully demonstrating the power and capabilities of RFID systems to automatically and reliably identify pallets and cases as they are moved throughout the military's supply chain. The automated asset identification that can be obtained by the use of RFID technologies will provide significant asset visibility improvements over the existing human/barcode technologies and processes.

The limitations of existing technologies were evident throughout the set-up of the Demonstration. These limitations indicated that significant engineering, development, and operating process redesign must be undertaken to fully utilize the RFID and EPC technologies and to realize their benefits.

The demonstrated RFID technologies were found to be very early in their development cycles. All technologies must undergo significant engineering and development to make them amenable to large-scale in-theater deployments. The tags must survive and operate through the life of the assets, including in normal handling that includes hostile environments. The tag failure rates in the demonstration were unacceptably high for normal operational deployments let alone large-scale in-theater deployments. Subsequent generations of RFID technologies are expected to benefit from improved and stabilized manufacturing. This will improve the dependability and reliability of the RFID systems.

Similarly, the readers are early in their development cycles. Deployed readers must operate in and survive harsh environments. The demonstration readers were not hardened, nor do hardened versions exist. Therefore, they were susceptible to damage from environmental conditions and accidental impacts. Hardened readers are expected to become commercially available in the near future.

Neither the antennae nor their mounts were hardened, thereby making the antennae susceptible to damage and reorientation. In addition, the deployment and configuration of the readers and antennae required expert installation and antenna positioning. Such expertise is not practical for in-theater deployments. The reader systems must be designed for simple deployments by non-experts.

The physical limitations of the operation of the RFID system will impact how work is performed. To take full advantage of RFID systems, the operating processes must be designed to work within the limitations of the technology. New processes must reduce operational complexity and be intuitive for the persons executing them.